APPLICATION NO. 10/772,597

INVENTION: Decisioning rules for turbo and convolutional decoding

INVENTORS: Urbain A. von der Embse

Clean version of how the CLAIMS will read

APPLICATION NO. 10/772,597

INVENTION: Decisioning rules for turbo and convolutional decoding

INVENTORS: U~~.~~rbain A. von der Embse

CLAIMS

WHAT IS CLAIMED IS:

Claim 1.(currently amended) A means for the new turbo decoding a-posteriori probability p(s,s'|y) in equations **(13)** of the invention disclosure of the decoder trellis states s',s for the received codeword k-1,k conditioned on the received symbol set y = {y(1),y(2),. . .,y(k-1),y(k),. . .,y(N)} for defining the maximum a-posteriori probability MAP in turbo decoding and which comprises:

~~provide~~ using a new statistical definition of the MAP — logarithm likelihood ratio L(d(k)|y) in equations **(18)** ~~in the~~

$$L(d(k))|y) = \ln[\ \Sigma_{(s,s'|d(k)=+1)}\ p(s,s'|y)] - \ln[\ \Sigma_{(s,s'|d(k)=-1)}\ p(s,s'|y)\ ]$$

~~invention disclosure~~ equal to the natural logarithm of the ratio of the a-posteriori probability p(s,s'|y) summed over all state transitions s'→s corresponding to the transmitted data d(k)=1 to the p(s,s'|y) summed over all state transitions s'→s corresponding to the transmitted data d(k)=0,

~~provide a means for~~using a factorization of the a-posteriori p(s,s'|y) into the product of the a-posteriori probabilities p(s'|y(j<k)), p(s|s',y(k)), p(s|y(j>k))

$$p(s,s'|y)=p(s|s',y(k))p(s|y(j>k))p(s'|y(j<k)),$$

~~provide a means for the~~ using a turbo decoding forward recursion equation for evaluating ~~the~~ said a-posteriori probability ~~-~~$p(s'|y(j<k))$ using said $p(s|s',y(k))$ as the state transition a-

$$p(s|y(j<k),y(k))= \sum_{\text{all } s'} p(s|s',y(k))\ p(s'|y(j<k))$$

posteriori probability of the trellis transition path $s' \rightarrow s$ to the new state s at k from the previous state s' at k-1 and given the observed symbol y(k) to update these recursions for the assumed value of d(k) equivalent to the transmitted symbol x(k) which is the modulated symbol corresponding to d(k),

~~provide a means for the~~using a turbo decoding backward recursion equation for evaluating ~~the~~ said a-posterior probability $p(s|y(j>k))$ using said $p(s'|s,y(k))$ as the state transition a-posteriori probability

$$p(s'|y(j>k-1)= \sum_{\text{all } s} p(s|y(j>k))p(s'|s,y(k))$$

~~priori probability~~ of the trellis transition path $s \rightarrow s'$ to the new state s' at k-1 from the previous state s at k and given ~~the~~ said observed symbol y(k) to update these recursions for ~~the~~ said assumed value of d(k) equivalent to ~~the~~ said transmitted symbol x(k) which is the modulated symbol corresponding to said d(k) and where said $p(s'|s,y(k))=p(s|s',y(k))$,

~~provide a means for~~ evaluating the natural logarithm of the state ~~-~~transition a-posteriori probability $p(s|s',y(k))= p(s'|s,y(k))$ as a function which is linear in the received symbol y(k)

$$\ln[p(s|s',y(k)) = \mathrm{Re}[y(k)x^*(k)]/\sigma^2 - |x(k)|^2/2\sigma^2 + p(d(k))$$

and wherein p is the natural logarithm ln of p, x* is the compolex conjugate of x, and ln[o] is the natural logarithm of [o],

~~provide a means for~~ evaluating ~~the~~ said natural logarithm of the said state transition a-posteriori probability p(s'|s,y(k)) ~~=~~ p(s|s',y(k)) equal to the ~~sum of the~~ new decisioning metric DX in equations **(11),(16)** ~~in the invention disclosure and the natural logarithm of the a-priori probability p(d(k)) equal to~~

$$\begin{aligned}\ln[p(s|s',y(k))] &= \ln[p(s'|s,y(k))] \\ &= \mathrm{Re}[y(k)x^*(k)]/\sigma^2 + |x(k)|^2/2\sigma^2 + p(d(k) \\ &= DX\end{aligned}$$

$$\cancel{DX = \mathrm{Re}[y(k)x^*(k)]/\sigma^2 + |x(k)|^2/2\sigma^2 + \ln[p(d(k))}$$

and which is linear in said received symbol y(k), ~~in which ln[(o)] is the natural logarithm of (o) and x*(k) is the complex conjugate of x(x) and the new decisioning metric DX is linear in y(k)~~

~~provide a means for the~~said new state transition probabilities in ~~the~~said MAP equations ~~to~~ use ~~the~~ said ~~new decisioning metric~~ DX ~~in equations **(11),(16)** in the invention disclosure DX = Re[y(k)x*(k)]/σ² + |x(k)|²/2σ²~~ linear in y(k) in place of the current use of the maximum likelihood decisioning metric DM ~~equal to~~

$$DM = [\ -|y(k) - x(k)|^2/2\sigma^2\ ],$$

which is a quadratic function of y(k),

~~provide a means for the natural logarithm of the state transition probability in the turbo decoding equations~~

~~tobe a linear function of y(k) in place of the current quadratic function of y(k)~~

~~provide a means for the~~said MAP turbo decoding algorithms ~~to~~ realizes some of the performance improvements demonstrated in FIG. **5,6** using ~~the new decisioning metrics~~said DX ~~in the invention disclosure~~ and,

~~provide a means for a new a-posterior mathematical paradym which enables the MAP turbo decoding algorithms to be restructured to allow the natural logarithms of the decisioning metrics to be linear in the detected symbols in place of the current quadratic dependency on the detected symbols~~

~~provide a means for a~~ said new a-posteriori mathematical ~~paradym~~ framework ~~which~~enables ~~the~~ said MAP turbo decoding algorithms to be restructured and to determine the intrinsic -information as a function of ~~the new decisioning metrics~~said DX linear in ~~the~~ said ~~detected symbols~~y(k).

Claim 2. (currently amended) ~~A~~ Wherein in claim **1** a means for ~~the~~ said new convolutional decoding in said MAP a-posteriori probability p(s,s'|y) ~~in equations **(13)** of this invention disclosure, of the decoder trellis states s',s for the received codeword k-1,k conditioned on the received symbol set y = {y(1),y(2),. . .,y(k-1),y(k),. . .,y(N)} for defining the state transition metrics in the forward and backward recursive equations for convolutional decoding~~ and which comprises:

~~provide a means for the new maximum a-posteriori probabilityf(x|y) of the transmitted symbol x given thereceived symbol y to replace the current maximum likelihood probability f(y|x) used for convolutional decoding of the received symbol y given the transmitted symbol x~~

~~provide a means for the~~using a new maximum a-posteriori principle which maximizes the a-posteriori probability ~~f~~$p(x|y)$ of the transmitted symbol x ~~with respect to the transmitted symbol x~~ given the received symbol y to replace the current maximum likelihood principle which maximizes the likelihood probability ~~f~~$p(y|x)$ of y given x ~~with respect to the transmitted symbol x~~ for deriving the forward and the backward recursive equations to implement convolutional decoding, ~~and in which f(x|y) is the a-posteriori probability of the transmitted symbol x given the observed symbol y and in which f(y|x) is the likelihood funcion which is the probability of the observed symbol y given the transmitted symbol x~~

~~provide a means for a~~using said factorization of ~~the~~ said a-posteriori $p(s,s'|y)$ into the product of ~~the~~ said a-posteriori probabilities $p(s'|y(j<k))$, $p(s|s',y(k))$, $p(s|y(j>k))$ to identify the convolutional decoding forward state metric $a_{k-1}(s')$, backward state metric $b_k(s)$, and state transition metric $p_k(s|s')$ as the a-posteriori probability factors

$$
\begin{aligned}
p_k(s|s') &= p(s|s',y(k)) \\
b_k(s) &= p(s|y(j>k)) \\
a_{k-1}(s') &= p(s'|y(j<k)),
\end{aligned}
$$

~~provide~~ using a ~~means for the~~ convolutional decoding forward recursion equation for evaluating ~~the~~ said a-posteriori – probability $a_k(s)=p(s|y(j<k),y(k))$ using said $p_k(s|s')=p(s|s',y(k))$ as ~~the~~ said state transition probability of the trellis transition path $s'\rightarrow s$ to the new state s at k from the previous state s' at k-1, ~~and given the observed symbol y(k) to update these recursions for the assumed value of d(k) equivalent to the assumed value for x(k) corresponding to d(k)~~

~~provide a means for the~~using a convolutional decoding backward recursion equation for evaluating ~~the~~ said a-posteriori probability $b_k(s)=p(s|y(j>k))$ using said $p_k(s'|s)=p(s'|s,y(k))$ as ~~the~~ said state transition probability of the trellis transition path $s \rightarrow s'$ to the new state s' at k-1 from the previous state s at k, ~~and given the observed symbol y(k) to update these recursions for the assumed value of d(k) equivalent to the assumed value for x(k) corresponding to d(k)~~

~~provide a means for~~ evaluating the natural logarithm of ~~the~~ said state transition a-posteriori probabilities $\ln[p_k(s'|s)]= \ln[p(s'|s,y(k))]= \ln[p(s|s',y(k))]=\ln[p_k(s|s')]$~~,~~ ~~as a function which is linear in the received symbol y(k)~~equal to said DX and,

~~provide a means for evaluating the natural logarithm of the statetransition a-posteriori probabilities ln[p(s'|s,y(k))]= ln[p(s|s',y(k))] equal to the sum of the new decisioning metric DX in equations (11),(16) in the invention disclosure and the natural logarithm of the a-priori probability p(d(k)) equal to~~

$$\cancel{\ln[p(s'|s,y(k))] = \ln[p(s'|s,y(k))]}$$

$$\cancel{= DX + \ln[p(d(k))]}$$

$$\cancel{DX = Re[y(k)x^*(k)]/\sigma^2 + |x(k)|^2/2\sigma^2}$$

~~in which ln[(o)] is the natural logarithm of (o) and x*(k) is the complex conjugate of x(x) and the new decisioning metric DX is linear in y(k)~~

~~provide a means for the state transition probabilities in theconvolutional decoding equations to use the new decisioning metric~~ $\cancel{DX=Re[y(k)x^*(k)]/\sigma^2+|x(k)|^2/2\sigma^2}$ ~~in equations (11),(16) in the invention disclosure in place of the current use of the maximum likelihood decisioning metric equal to~~ $\cancel{[-|y(k) - x(k)|^2/2\sigma^2]}$

~~provide a means for the natural logarithm of the state transitionprobability in the convolutional decoding~~

~~equations to be a linear function of y(k) in place of the current quadratic function of y(k)~~

~~provide a means for the~~said convolutional decoding algorithms ~~to~~ realize some of the performance improvements demonstrated in FIG. **5,6** using ~~the new decisioning metrics in this~~said ~~invention disclosure~~DX.

~~provide a means for a new a-posteriori mathematical paradym whichenables the convolutional decodingalgorithms to be restructured to allow the natural logarithms of the decisioning metrics to be linear in the detected symbols~~

Claim **3**. (currently amended) Wherein in claim **1** A means for the new convolutional decoding recursive equations which calculate said MAP a-posteriori probability p(s,s'|y) ~~in equations **(13)** of the invention disclosure of the decoder trellis states s',s for the received codeword k-1,k conditioned on the received symbol set y = {y(1),y(2),. . .,y(k-1),y(k),. . .,y(N)} for replacing the current probability p(s,s',y) for turbo decoding and for convolutional decoding when the natural logarithm of the a-priori probability is set equal to zero meaning ln[p(d)]=ln[p(x)]=0~~ and which comprises:

~~provide a means for a factorization of the a-posterioriprobability p(s,s'|y) into the product of the a-posteriori probabilities a_{k-1}, b_k, p_k defined in equations (13) in the invention disclosure~~

~~a_{k-1} = p(s'|y(j<k))~~

~~b_k = p(s|y(j>k))~~

~~p_k = p(s|s',y(k))~~

~~and the natural logarithms are $\underline{a}_{k-1}$=ln[a_{k-1}], $\underline{b}_k$=ln[b_k], $\underline{p}_k$=ln[p_k] and replacing the current factorization of p(s,s',y) into the product of the α_{k-1}, β_k, γ_k in equations **(3)** in the background art~~

~~$\alpha_{k-1}(s')$ = p(s',y(j<k))~~

~~$\beta_k(s)$ = p(y(j>k)|s)~~

~~$\gamma_k(s,s') = p(s,y(k)|s')$~~

~~and the natural logarithms are $\underline{\alpha}_{k-1}=\ln[\alpha_{k-1}]$, $\underline{\beta}_k=\ln[\beta_k]$, $\underline{\gamma}_k=\ln[\gamma_k]$~~

~~provide a means for the~~said forward recursion equation for ~~-~~evaluating said natural log, a_k, of a_k using said $p_k=\ln[p(s|s',y(k))]$ as the natural logarithm ~~of the~~said state transition a-posteriori probability of the trellis transition path s'→s to the new state s at k from the previous state s' at k-1 ~~and given the observed symbol y(k) to update these recursions for the assumed value of d(k) equivalent to the transmitted symbol x(k) which is the modulated symbol corresponding to d(k)~~ and is

$$a_k(s) = \max_{s'}[a_{k-1}(s') + p_k(s|s')]$$

$$= \max_{s'}[a_{k-1}(s') + DX(s|s')]$$

$$= \max_{s'}[a_{k-1}(s') + \mathrm{Re}[y(k)x^*(k)]/\sigma^2 - |x(k)|^2/2\sigma^2 + p(d(k))]$$

wherein said $DX(s|s')=p_k(s|s')]=p_k(s'|s)=DX(s'|s)=DX$ is said new decisioning metric,

~~replacing the current forward recursive equation for evaluating the forward recursion equation for $\underline{\alpha}_k$ using $\underline{\gamma}_k(s,s') = \ln[p(s,y(k)|s')]$ as the natural logarithm of the state transition probability of the trellis transition path s'→s to the new state s at k from the previous state s' at k-1 and the probability of the observed symbol y(k).~~

~~provide a means for th~~said ~~e~~ backward recursion equation for evaluating said b_k using said $p_k=\ln[p(s'|s,y(k))]=\ln[p(s|s',y(k))]$ as the natural logarithm of ~~the~~ said state transition a-posteriori

probability of the trellis transition path $s \rightarrow s'$ to the new state s' at $k-1$ ~~from the previous state s at k and given the observed symbol $y(k)$ to update these recursions for the assumed value of $d(k)$ equivalent to the transmitted symbol $x(k)$ which is the modulated symbol corresponding to $d(k)$~~ and is

$$b_{k-1}(s') = \max_{s} [b_k(s) + DX(s'|s)] \text{ and,}$$

~~replacing the current forward recursive equation for evaluating the forward recursion equation for β_k using $\gamma_k(s,s') = \ln[p(s,y(k)|s')]$ as the natural logarithm of the state transition probability of the trellis transition path $s' \rightarrow s$ to the new state s at k from the previous state s' at $k-1$ and the probability of the observed symbol $y(k)$~~

~~provide a means for evaluating the natural logarithm of the statetransition a-posteriori probability $p(s|s',y(k)) = p(s'|s,y(k))$ as a function which is linear in the received symbol $y(k)$~~

~~provide a means for evaluating the natural logarithm of the statetransition a-posteriori probability p_k equal to the sum of the new decisioning metric DX in equations (11), (16) in the invention disclosure and the natural logarithm of the a-priori probability $p(d(k))$ equal to~~.

~~$p_k = DX + \ln[p(d(k))]$~~

~~$DX = \mathrm{Re}[y(k)x^*(k)]/\sigma^2 + |x(k)|^2/2\sigma^2$~~

~~and replacing the current natural logarithm of the state transition probability γ_k equal to the sum of the current decisioning metric DM in equations (1), (6) in the background art~~

~~$\gamma_k = DM + \ln[p(d(k))]$~~

~~DM = −|y(k)−x(k)|²/2σ²~~

~~and our new decisioning metric DX is linearly proportional to y(k) and the current decisioning metric DM is a quadratic function of y(k)~~

~~provide a means for the natural logarithm of the state transitionprobability in the turbo and convolutional decoding equations to be a linear function of y(k) in place of the current quadratic function of y(k)~~

~~provide a means for the~~said decoding algorithms ~~to~~ realize some of the performance improvements demonstrated in FIG. **5,6** using ~~the new decisioning metrics in this invention~~said DX. ~~disclosure~~

~~provide a means for a new a-posteriori mathematical paradym whichenables the decoding algorithms to berestructured to allow the natural logarithms of the decisioning metrics to be linear in the detected symbols~~

APPLICATION NO. 10/772,597

INVENTION: Decisioning rules for turbo and convolutional decoding

INVENTORS: Urbain A. von der Embse

Clean version of how the ABSTRACT will read

APPLICATION NO. 10/772,597

INVENTION: Decisioning rules for turbo and convolutional decodin

INVENTOR~~S~~: Urbain ~~Alfred~~ A. von der Embse

ABSTRACT OF THE DISCLOSURE

~~**ABSTRACT**~~

~~The present invention describes new~~ New and improved a-posteriori decoding probabilities, decisioning metrics, and implementation algorithms for turbo and convolutional ~~and turbo~~ decoding~~.~~ ~~Convolutional decoding algorithms for forward and reverse decoding use a maximum likelihood ML algorithm in a trellis architecture that determines a path metric based on decision metric measurements to find the best trellis path. This ML algorithm can be modified to a maximum a-posteriori MAP iterative algorithm for turbo decoding. Turbo decoding algorithms use the MAP path metrics based on decision metric measurements and a-priori probabilities over the observed data set in the form of a likelihood ratio, to implement iterative decoding. This invention replaces~~to replace the probabilities and decisioning metrics currently used in the maximum likelihood ML and maximum a-posteriori MAP algorithms~~, ~~. ~~with new and improved~~ A-posteriori probabilities p(x}y) replace the current ML probabilities p(y}x) wherein y is the received symbol and x is the transmitted data and the MAP a-posteriori probability $p(s',s|y)$ replaces the current MAP joint probability $p(s',s,y)$ wherein s',s are the trellis decoding states at $k-1,k$ and y is the observed data set $y(k), k = 1,2,\ldots,N$. This yields a-posteriori probabilities and decisioning metrics ~~that reduce the number of arithmetic multiply operations and thereby reduce the computational complexity,~~ to improve decisioning and bit error rate BER performance~~,~~ and to provide a new mathematical decoding framework. Complexity is the same as current implementations. ~~improve iterative convergence~~

~~thereby reducing compexity, improve bit error rate BER performance, and provide a new mathematical decoding paradigme. Complexity, iterations required for convergence, and BER tend to be key performance parameters of interest for most applications.~~